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METHOD FOR SELECTIVELY STRESSING MOSFETs
TO IMPROVE CHARGE CARRIER MOBILITY

FIELD OF THE INVENTION

001 This invention generally relates to formation of MOSFET devices in integrated circuit manufacturing processes and more particularly to a method of selectively inducing stress (strain) into a MOSFET device to improve both electron and hole charge carrier mobility in respective MOSFET channel regions.

BACKGROUND OF THE INVENTION

002 Mechanical stresses are known to play a role in charge carrier mobility which affects Voltage threshold shifts. The effect of induced mechanical stresses, also referred to as strain in MOSFET device channel regions, on charge carrier mobility is believed to be influenced by complex physical processes related to acoustic and optical phonon scattering.

003 Generally, manufacturing processes are known to introduce stress into the MOSFET device channel region. For example, stress is typically introduced into the channel region by formation of an overlying polysilicon gate structure and silicide

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formation processes. In addition, ion implantation and annealing processes following formation of the gate structure typically introduce additional stresses into the polysilicon gate structure which are translated into the underlying channel region altering device performance.

004 Prior art processes have attempted to introduce offsetting stresses into the channel region by forming stressed dielectric layers over the polysilicon gate structure following a silicide formation process. These approaches have met with limited success, however, since the formation of the stressed dielectric layer typically has a degrading electrical performance effect, for example drive current, on a CMOS device formed to operate on the opposite type of majority charge carrier (e.g., N vs. P charge carrier). For example, as NMOS device performance is improved, PMOS device performance is degraded.

005 Other shortcomings in prior art approaches are the adverse affect of the dielectric stress altering layer on subsequent gap filling ability of a subsequent inter-layer dielectric (ILD) layer deposition. For example, the thickness of the dielectric stress layer, and therefore stress altering

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influence, is limited due to the formation of narrower gaps between devices, a limitation that will increase as device sizes and gap sizes between devices decreases.

006 These and other shortcomings demonstrate a need in the semiconductor device integrated circuit manufacturing art for improved CMOS device manufacturing methods to control a mechanical stress level in CMOS device channel regions to improve device performance and reliability.

007 It is therefore an object of the present invention to provide improved CMOS device manufacturing methods to control a mechanical stress level in CMOS device channel regions to improve device performance and reliability, in addition to overcoming other shortcomings of the prior art.

SUMMARY OF THE INVENTION

008 To achieve the foregoing and other objects, and in accordance with the purposes of the present invention, as embodied and broadly described herein, the present invention provides a strained channel MOSFET device with improved charge mobility and method for forming the same.

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009 In a first embodiment, the method includes providing a first gate with a first semiconductor conductive type and second gate with a semiconductor conductive type on a substrate; forming a first strained layer with a first type of stress on said first gate; and, forming a second strained layer with a second type of stress on said second gate.

0010 These and other embodiments, aspects and features of the invention will be better understood from a detailed description of the preferred embodiments of the invention which are further described below in conjunction with the accompanying Figures.

BRIEF DESCRIPTION OF THE DRAWINGS

0011 Figures 1A-1F are cross sectional schematic representations of exemplary portions of a CMOS device including NMOS and PMOS portions formed in parallel at stages of manufacture according to an embodiment of the present invention.

0012 Figure 2 is an exemplary process flow diagram including several embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

0013 Although the method of the present invention is explained with reference to exemplary NMOS and PMOS devices, it will be appreciated that the method of the present invention may be applied to the formation of any MOSFET device where a stress level is controllably introduced into a charge carrier channel region by selective formation and subsequent removal of stressed dielectric layers overlying an NMOS and/or PMOS gate structure.

0014 Referring to Figures 1A-1F in an exemplary embodiment of the method of the present invention, are shown cross-sectional schematic views of a portion of a semiconductor wafer during stages in production of CMOS structures including NMOS and PMOS devices 10A and 10B. For example, referring to Figure 1A is shown a silicon substrate 12 including respective p-doped well regions 12A and n-doped well region 12B formed by conventional methods, for example a masking process followed by ion implantation and activation annealing. Formed by conventional processes prior to forming the n-well and p-well regions are isolation areas, for example shallow trench isolation (STI) structures, e.g., 14 back filled with an oxide dielectric, for example TEOS oxide.

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0015 Still referring to Figure 1A, a gate structure is formed by conventional processes including first depositing a gate dielectric portion e.g., 16A and 16B followed by formation of a polysilicon layer and photolithographic patterning and plasma assisted etching e.g., an (RIE) process to form polysilicon gate electrode portions e.g., NMOS device polysilicon gate electrode 18A and PMOS device polysilicon gate electrode 18B. Following formation of the polysilicon gate electrodes, source/drain extension (SDE) regions forming a portion of doped S/D regions e.g., 20A and 20B are formed by a conventional ion implant process adjacent the polysilicon electrodes to a shallow depth e.g., (30 to 100 nm) beneath the silicon substrate surface according to a low energy ion implantation or plasma immersion doping process.

0016 Still referring to Figure 1A, sidewall spacers e.g., 22A and 22B, also referred to as dielectric offset spacers, are formed along the polysilicon gate electrode sidewalls by depositing one or more layers of silicon nitride (e.g., Si_3N_4), silicon oxynitride (e.g., SiON), or silicon oxide (e.g., SiO_2) over the gate dielectric followed by etching away portions of the

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one or more layers to form self-aligned sidewall spacers on either side of the polysilicon gate electrodes.

0017 Following sidewall spacer formation, the NMOS and PMOS device areas are sequentially doped according to a conventional a high dose ion implantation (HDI) process to form the high density implant portions of doped source/drain (S/D) regions e.g., 20A and 20B in the silicon substrate adjacent the sidewall spacers. The polysilicon electrodes 18A and 18B are preferably doped at the same time the HDI is carried out to lower a sheet resistance of the polysilicon. The HDI process, carried out at higher implantation energies known in the art compared to the SDE ion implantations, preferably at least partially forms amorphous polysilicon in polysilicon electrodes 18A and 18B including the entire polysilicon electrode portion.

0018 In one embodiment, an annealing process to activate the HDI treated S/D regions and the polysilicon electrodes is postponed until after the formation of overlying dielectric films in tensile stress and/or compressive stress over respective NMOS and PMOS gate structures as explained further below.

0019 Referring to Figure 1B, according to an important aspect of the invention, at least one first dielectric layer e.g., 24A is blanket deposited to cover the NMOS and PMOS structures formed in one of compressive and tensile stress to form a first strained layer. Prior to formation of the first dielectric layer 24A, optionally, but preferably to enhance a subsequent etch processes, a silicon oxide buffer layer e.g., 23 having a thickness of less than about 200 Angstroms is formed by a conventional CVD process over the NMOS and PMOS devices. It will be appreciated, as explained below, that the order of first depositing dielectric (strained) layers in either tensile (over NMOS device) or compressive stress (over PMOS device) may be reversed provided that a tensile stress dielectric layer is formed over the NMOS device portion and/or the compressive stress dielectric layer is formed over the PMOS device portion, prior to the dopant activation and polysilicon recrystallization annealing process.

0020 In the exemplary embodiment as shown, the first dielectric layer 24A is deposited in tensile stress over both the NMOS device and PMOS devices. For example, the first dielectric layer is deposited to be in tensile stress, having a tensile

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stress, preferably of up to about 2 GPa. It will be appreciated that the level of the tensile stress can be varied by a number of factors including the thickness of the dielectric film, preferably being from about 50 Angstroms to about 1000 Angstroms in thickness. In a preferred embodiment, the dielectric film 24A is deposited by a CVD process where the relative reactant flow rates, deposition pressure, and temperature may be varied to vary a composition of the dielectric layer thereby controlling the level of either tensile or compressive stress. For example, the dielectric film may be a nitride film, preferably including silicon nitride (e.g., SiN, Si_xN_y) or silicon oxynitride (e.g., Si_xON_y) where the stoichiometric proportions x and y may be selected according to CVD process variables as are known in the art to achieve a desired tensile or compressive stress in a deposited dielectric layer. For example, the CVD process may be a low pressure chemical vapor deposition (LPCVD) process, an atomic layer CVD (ALCVD) process, or a plasma enhanced CVD (PECVD) process.

0021 According to an aspect of the invention the first dielectric layer 24A is deposited at a temperature lower than a recrystallization temperature of the amorphous polysilicon gate

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electrode 18A and 18B portions formed in the HDI process. For example, although the precise recrystallization temperature is dependent on the level and type of doping, deposition at a temperature of less than about 600 °C is generally sufficient to prevent recrystallization of the amorphous polysilicon gate electrode portions. Conventional CVD precursors such as, silane (SiH_4), disilane (Si_2H_6) dichlorosilane (SiH_2Cl_2), hexachlorodisilane (Si_2Cl_6), BTBAS and the like, may be advantageously used in the CVD process to form the first dielectric layer.

0022 For example, a low temperature LPCVD process for forming a tensile stress nitride dielectric layer includes supplying hexachlorodisilane (HCD) (Si_2Cl_6) and NH_3 gaseous precursors deposited at a temperature of from about 400 °C to about 600 °C at a pressure of about 0.1 Torr to about 10 Torr mTorr. An NH_3 to HCD volumetric gas ratio is from about 0.1 to about 500 with a stress increasing with an increasing volumetric ratio.

0023 For example, a low temperature PECVD process for forming a compressive stress nitride layer may include supplying silane (SiH_4) and NH_3 gaseous precursors at a deposition temperature of

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from about 300 °C to about 600 °C carried out at pressures of from about 50 mTorr to about 5 Torr and RF powers of from about 100 Watts to about 3000 Watts. The RF power frequency is from about 50 KHz to about 13.56 MHz. Compressive stress increases with increasing power and frequency.

0024 Referring to Figure 1C, following formation of the first dielectric layer 24A, a resist patterning process is carried out to cover one of the NMOS and PMOS device portions and remove the first dielectric layer remaining exposed over the uncovered portion. For example, in the exemplary order of processing steps shown, a protective resist covering 25A is formed over the NMOS device portion 10A and the first dielectric layer 24A formed in tensile stress is removed over the PMOS device portion 10B, e.g., including over about half the width of the STI feature 14 by a conventional wet etching (e.g., HF or hot H₃PO₄) or dry etching process.

0025 At this point, an annealing process is optionally carried out to simultaneously activate the HDI dopants in the polysilicon gate electrodes 18A and 18B and S/D regions e.g., 20A and 20B as well as recrystallize the amorphous polysilicon gate electrode

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portions formed in the HDI process. For example, the annealing process is preferably carried out at temperatures greater than about 600 °C, more preferably greater than about 900 °C by conventional annealing techniques. During the annealing process and recrystallization of the amorphous polysilicon portions, the stressed (strained) dielectric layer e.g., 24A enhances a stress, e.g., tensile stress imparted to the respective channel region e.g., 12A while not affecting (enhancing) the stress (e.g., compressive) imparted to the channel region of the device (e.g., PMOS) having the stressed dielectric layer first removed, thereby enhancing electron mobility in the NMOS device while not degrading electron mobility in the PMOS device.

0026 It will be appreciated that a compressive stress dielectric layer may be first formed over the NMOS and PMOS devices 10A and 10B followed by removal of that portion of the compressive stress dielectric layer overlying the NMOS device 10A portion followed by an annealing process to impart an enhanced compressive stress to the PMOS channel 10B portion e.g., 12B to enhance hole mobility, while not degrading electron mobility in the NMOS device.

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0027 In one embodiment, following the annealing process, the remaining portion of the first dielectric layer 24A overlying the NMOS device 10A and the oxide buffer layer 23 over both NMOS and PMOS devices may be removed, for example by sequential wet etching (e.g., hot H_3PO_4 dip) or dry etching, followed by a dilute HF wet etching solution dip to remove remaining portions of the oxide buffer layer 23.

0028 Referring to Figure 1D, in another embodiment, following removal of a portion of the first dielectric layer 24A (e.g., in tensile stress over the PMOS device 10B), at least one second strained (stressed) dielectric layer 24B is formed over the NMOS device 10A and PMOS device 10B according to preferred embodiments as outlined for the first dielectric layer 24A, but now preferably formed in an opposite stress relationship, e.g., compressive stress up to about 2 GPa.

0029 Referring to Figure 1E, a second protective resist layer 25B is then deposited to cover and protect the PMOS device 10B portion while a portion of the second dielectric layer 24B overlying the NMOS device portion 10A is removed according to a conventional wet or dry etching process as previously outlined

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for dielectric layer portion 24A. For example, for a silicon nitride containing second dielectric layer 24B, a wet etching process including HF and/or hot H_3PO_4 , or a fluorocarbon and/or hydrofluorocarbon containing dry etching chemistry.

0030 At this point, after forming a respective tensile stress dielectric layer e.g., 24A over the NMOS device and a compressive stress dielectric layer e.g., 24B over the PMOS device, an annealing process is not necessary if the respective dielectric layers will remain in place to form a protective layer, e.g., a contact etching stop layer in subsequent processes. On the other hand, if the stressed dielectric layers 24A and 24B are desired to be removed to improve a subsequent gap filling process, prior to removal, an annealing process, similar to that previously outlined is preferably carried out to recrystallized amorphous polysilicon portions with the respective stressed dielectric layers in place over one or both of the NMOS and PMOS devices to transfer a stress to the channel region to form a strained channel thereby improving the charge carrier mobility in at least one and preferably both NMOS and PMOS devices.

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0031 Advantageously, following formation of the respective tensile stress and compressive stress dielectric layers, e.g., 24A and 24B are left in place to serve both stressors and as protective layers in subsequent manufacturing processes.

0032 Referring to Figure 1F, in a another embodiment, if the dielectric layer portions 24A and 24B are removed, and oxide buffer layer 23, conventional processes may then carried out to complete formation of the NMOS and PMOS MOSFET devices including forming salicide (self aligned silicide) portions over the source and drain regions e.g., 28A and 28B, and silicide over the upper portion of the polysilicon electrodes, e.g., 30A and 30B. For example, TiSi_2 or CoSi_2 silicides are formed by conventional processes including titanium or cobalt deposition followed by silicide formation and annealing processes to achieve the low electrical resistance silicide phase as is known in the art.

0033 Referring to Figure 2 is a process flow diagram including several embodiments of the present invention. In process 201, a an semiconductor substrate including a polysilicon gate electrode is provided. In process 203 a high density implant (HDI) doping process is carried out inducing polysilicon gate electrode

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amorphization. In process 205, at least one dielectric layer in tensile and/or compressive stress over respective NMOS and PMOS polysilicon electrodes (i.e., tensile stress over NMOS and/or compressive stress over PMOS). In process 207, an annealing process is carried out to activate the HDI dopants and recrystallize the polysilicon gate electrodes forming a desired stress in the semiconductor substrate. In process 209, the at least one dielectric layer is removed. In process 211, conventional processes are carried out to complete formation of MOSFET devices.

0034 Thus a method has been presented for selectively delivering a selected stress level and type to a MOSFET channel region to improve charge carrier mobility and device performance. Among the several advantages of the invention include the fact that the stressed dielectric layer may be deposited at higher temperatures since the deposition temperature is limited by a temperature of amorphous polysilicon recrystallization rather than another phase transformation such as a previously formed salicides. Further, since the HDI dopant activation is carried out following formation of the stressed dielectric layer, the temperature of dielectric layer formation does not contribute to dopant deactivation. Moreover, an embodiment of the method of

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the present invention allows the simultaneous formation of a desired level and type of stress in both PMOS and NMOS devices to improve both hole and electron charge carrier mobility, respectively.

0035 Other realized advantages include the fact that the stressed dielectric layers may be removed following the stressed channel enhancing process thereby avoiding process window limitations including gap filling ability in a subsequent ILD layer deposition process. Alternatively, portions of the stressed dielectric layers may be left in place to serve as both stressors and protective layers without the necessity of additional formation processes. Advantageously, the method is cost efficient in that the same photomask used for respective NMOS and PMOS HDI processes may be used to selectively remove stressed dielectric layer portions followed by formation of stressed dielectric layer over respective NMOS and PMOS devices.

0036 The preferred embodiments, aspects, and features of the invention having been described, it will be apparent to those skilled in the art that numerous variations, modifications, and substitutions may be made without departing from the spirit of the invention as disclosed and further claimed below.